APPENDIX 8-6

SEEPAGE CONTROL TECHNICAL MEMORANDUM

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BLACK & VEATCH

TECHNICAL MEMORANDUM

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Task 16.19 Seepage Control Technical Memorandum

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1. INTRODUCTION

1.1 Background

In October 2003, South Florida Water Management District (District) decided to pursue a "Dual Track" for the Everglades Agricultural Area (EAA) Reservoir project. While the multi-agency Project Delivery Team, lead by the US Army Corps of Engineers (USACE), continues to develop the Project Implementation Report (PIR), the District is proceeding with the design of a reservoir (designated EAA Reservoir A-1 Project) located on land acquired through the Talisman exchange in the EAA.

The EAA Reservoir A-1 Project is located in Palm Beach County with a total storage capacity of approximately 190,000 acre-feet with a maximum storage depth of water to be approximately 12 feet.

The purpose of the full EAA Reservoir Project, as defined in the CERP, is to capture EAA Basin runoff and releases from Lake Okeechobee. The facilities will be designed to improve the timing of environmental water supply deliveries to STA 3/4 and the WCAs, reduce Lake Okeechobee regulatory releases to the estuaries, meet supplemental agricultural irrigation demands, and increase flood protection within the EAA.

To proceed with implementation of the EAA A-1 Reservoir, the District selected Black & Veatch from the General Engineering Services Contracts, Full Services to complete the 30% design services for the EAA Reservoir A-1 and associated pump stations.

This Seepage Control Technical Memorandum follows a Test Cell Program which was carried out to provide a basis for key design criteria for the EAA Reservoir A-1 Project. Other results from the Program are reported in Reservoir Seepage Analysis Technical Memorandum, Test Cell Construction and Seepage Monitoring Report, Reservoir Configuration Memorandum, and the Embankment Technical Memorandum. These Technical Memoranda have been developed in parallel to this stage and this memorandum does not describe or include the recommendations from the others. The next stage of the design process will bring the different facets together in a single recommended design solution.

1.2 Previous Studies

It is not traditional to store water as deep as 12' above ground level in the Everglades area. Seepage control or mitigation (prevention) is a primary design issue to be considered. A seepage cutoff wall is a traditional seepage control measure for reservoir sites containing subsurface stratification with high permeabilities. The perimeter length of embankment at Reservoir A-1 and potential depth required to achieve an effective cutoff could make a seepage cutoff wall a significant economic factor to be considered in the reservoir design. The results of the previous modeling presented in the Report for Conceptual Levee High Alternatives (CLHA Report) indicate that a slurry wall could be effective in reducing seepage losses from the reservoir and the seepage collected for recycling into the reservoir is reduced.

Recoverable seepage refers to the amount of water which is collected in the seepage canals and re-pumped into the reservoir. Based on seepage amounts listed in the CLHA Report, a cutoff wall under the embankment would reduce overall seepage and eliminate the need for re-pumping 55 cfs at the peak condition. The confidence level expressed in the subject report was very low as demonstrated by the statement that permeabilities could vary by a factor of 10 to 100 or more.

Subsurface data presented in the CLHA Report indicates variability in the number, thickness, and sequence of individual substrata across the reservoir site. The evaluation of seepage potential and the effectiveness of control measures using typical test well analysis procedures can be misleading unless the variability in site conditions is appropriately considered. The description of geologic conditions includes three substantial units below the surficial muck/peat and marl within the upper 200 feet of the surface including, in descending order: Fort Thompson Formation (including the caprock), the Caloosahatchee Formation and the Tamiami Formation. These units are considered to contain many layers of different hydrological characteristics as a result of the varying conditions during past depositional and erosional environments. Definition of the appropriate subsurface model to evaluate the seepage potential from the reservoir is significantly complicated by the variability in the subsurface stratification.

1.3 Objectives

The objectives of this Seepage Control Technical Memo are to:

- Develop and analyze seepage control alternatives in the area near the dam
- Prepare recommendations for controlling seepage to be used in further studies and design

The Test Cell program was to effectively evaluate the reservoir seepage potential by obtaining the data required for the development of a model which is not dependent on the hydrogeologic characteristics of a single geologic unit. The test cell program was designed to develop hydraulic conductivity data or the average mass hydraulic conductivity value of a geologic unit thereby reducing the variables to be considered to unit thickness, cutoff depth and location, and depth and operating level of the seepage collection canal, if required.

The hydraulic conductivity values and seepage control measures considered appropriate as a result of the test cell program will be input into the reservoir seepage and mass balance model. Additional hydraulic modeling using measured flow into the seepage collection canal will be required to determine the proper sizing of the inflow pump stations located on the collection canal.

1.4 Supplementary Work

Following the original release of this Technical Memorandum the groundwater control and seepage studies were extended. Much of the supplementary work was carried out using the MODFLOW computer program and is described in the Work Order 7 Groundwater Model Technical Memorandum.

The generic seepage control issues described and discussed herein are independent of the dam type that will eventually be selected for construction. The work described in this Technical Memorandum was carried out using SEEP/W. Where two dimensional analyses are appropriate this computer program will continue to be used to study the pore water pressures and hydraulic gradients close to the dam and associated structures.

2. FOUNDATION SEEPAGE CONTROL ALTERNATIVES

2.1 General

The aim of the foundation seepage control alternatives are to mitigate seepage losses from the reservoir to protect the foundation from possible damage by piping and minimize excess uplift pressures to enhance stability. Historically the mode of operation low head water control facilities in the area has been to accept seepage and return it by pumping. Several different configurations are possible : key trench, cut-off wall or upstream blanket and distance between the reservoir and seepage collection canal. These options are described below. Each alternative has a different efficiency and a different cost; the ultimate solution will balance these factors. See Figure 1.

2.2 Key Trench

A key trench, or core trench, cutoff would be shallow and broad, excavated through the caprock and extended into the underlying silty sand. This alternative would effectively reduce the high horizontal seepage only through the caprock. The sides of the key trench would typically be sloped. The trench would extend through the caprock layer into the less pervious silty sand layer. Dewatering would be required to excavate and backfill the key trench. A key trench is typically located at the embankment centerline or some distance upstream of the embankment centerline.

The minimum width of key trench would be governed by the hydraulic gradient across the base of the trench. Limiting the gradient reduces the chance of hydraulic fracture or piping. Additional protection of the fill against piping would be required on the downstream side of the trench because of potential open areas or voids and channels through the cap rock. This protection could be provided either by shotcreting the inclined slope or laying a filter layer against it.

2.3 Cutoff Wall

A cutoff wall could be used to reduce the horizontal groundwater flow through multiple strata and force seepage to penetrate at depth before exiting the reservoir perimeter. A foundation cutoff can be installed below the water table using the slurry method of trench excavation. The method involves excavating a trench below the water table and maintaining trench stability with a mixture of water and bentonite. Except for very deep trenches, cutoff trenches are typically excavated with hydraulic excavators.

For a standard slurry trench the backfill for the wall is typically mixed on the ground surface adjacent to the cutoff. The backfill generally consists of a mixture of the excavated trench soils and processed commercial bentonite. A soil-bentonite cutoff wall is the most economical when suitable site soils are available for use as backfill. Other types of wall backfill options include soil-cement-bentonite, cement-bentonite, and plastic concrete. These alternatives would be appropriate where differential movement could be expected between a rigid concrete dam and the trench backfill.

Cutoff walls are typically located at the center of the dam or, depending on the dam configuration, at the upstream toe of slope (for instance with a concrete faced rockfill dam). It is important to ensure continuity between the watertight barrier in the dam and the subsurface cutoff, so the junction between the two elements is critical.

The caprock at the test cell site was observed to have solution voids and channels. Many of the vertical solution channels were circular, ranging in diameter from a fraction of an inch to several inches, and extended all the way through the caprock. As described in the Test Cell Program Technical Memorandum, the boils that occurred at Test Cell 1 appeared to be associated with these holes. Most of the solution channels were vertical. However, there are bedding planes and more porous layers of limestone present within the caprock unit. These porous layers contain horizontal solution channels but the continuity of these channels is not known. Open, horizontal solution channels in the caprock present a danger that piping of the slurry material in the cutoff wall could occur. The interface between the cutoff wall and the caprock must either be sealed or a filter provided. The choice of protection depends on construction methodology.

Different cutoff wall depths (shallow caprock cutoff, cutoff through the Fort Thompson Formation, and the cutoff extending into the Caloosahatchee Formation) were modeled in the comparison of seepage control alternatives described below as a preliminary evaluation of the alternatives.

2.3.1 Shallow Cutoff Through Caprock Beneath Embankment

A shallow cutoff wall or trench through the caprock and extending a few feet into the underlying silty sand could represent a minimum cutoff wall depth. The purpose of this wall would be to only cutoff flow through the caprock layer to control seepage that might otherwise cause piping of the embankment soil and foundation soil. This alternative has been considered below for completeness. It is not a recommended design solution.

Test Cell 1, as described in the Test Cell Program Technical Memorandum, demonstrated the vulnerability of the foundations when no cutoff wall is provided. On Test Cell 1, boils quickly developed on the downstream side of the embankment. Therefore, long-term seepage could potentially develop into uncontrolled piping of the sandy silt/silty sand soils underlying the caprock around the perimeter of the reservoir. The general conditions around Test Cell 1 have a high potential to develop piping for an embankment with a significant design life.

Reservoir A-1 presents a significantly more difficult surveillance challenge than most dams which are much shorter. Most dams are routinely inspected closely on foot for signs of deterioration. Such close scrutiny will be hard to maintain in these circumstances, so conditions that represent a future vulnerability, such as potential boils and aggressive leakage, should be mitigated.

In view of this we would recommend that a deeper cutoff wall is provided of comparable depth to that provided for Test Cell 2. The final depth will be selected following further design development and study. The shallow cutoff alternative (only extending a few feet below caprock) has been studied to better understand seepage quantity, but it is not a recommended design option.

2.3.2 Cutoff through Fort Thompson beneath Embankment

This alternative is similar to the cutoff wall that was constructed at Test Cell No. 2. The cutoff would be extended to the base of the Fort Thompson Formation. In Test Cell No. 2, the cutoff was stopped at a depth slightly less than 30 feet on the top of the shelly limestone layer that was encountered at approximately -16.0 feet elevation at the test cell site.

2.3.3 Cutoff Extending Into Calooshahatche Formation beneath Embankment

This alternative involves installing a cutoff wall to about 70 feet below the existing ground level. This alternative reduces seepage along the horizontal limestone and shell layer in the Fort Thompson Formation and forces seepage to pass more vertically through about 15 feet of the fine calcitic silty sand/sandy silt. The bottom elevation of this cutoff would be approximately -60.0 elevation. This cutoff wall installation may involve excavating through a limestone layer at the bottom of the Fort Thompson Formation as found in the test cell site.

2.4 Upstream Impervious Blanket

An upstream impervious blanket was evaluated as an alternative to a deep cutoff wall. An upstream blanket would either be constructed from silty sand (select fill) from the Fort Thompson Formation or by using a geomembrane with appropriate bedding protection from puncturing by large or sharp rocks. Either solution would require substantial protection from wave action. A soil blanket would also require protection from drying to prevent cracking in hot weather.

To avoid short circuiting by seepage paths, both solutions would require use of a shallow cutoff wall through the caprock layer at the upstream toe of the blanket. Although a blanket would be simple logistically to construct, it would require far more material than a vertical cutoff. Given the high ratio of horizontal to vertical permeability on this site, a blanket would need to be very long in order to have the same effect as a vertical wall.

3. MINIMIZING OFFSITE IMPACTS

3.1 General

In addition to the reasons associated with the dam to control seepage, i.e. quantity of water lost from the reservoir and structural integrity, it is necessary to control seepage so that other stakeholders are not affected by construction. These issues have been addressed further in the Groundwater Model Technical Memorandum. Specific cases around the reservoir site are described in Section 6. Generic seepage control solutions are described briefly below.

3.2 Seepage Cutoffs

A shallow seepage cutoff through the caprock on the exterior side of the seepage collection canal was evaluated. The purpose of the cutoff through the caprock was to limit offsite impacts of seepage collection canal pumping and reduce the amount of water drawn in to the system from surrounding land outside of the project boundaries.

3.3 Seepage Collection

Seepage from the reservoir will be collected in a seepage collection canal constructed parallel to the embankment alignment. On the south side of the Reservoir A-1, an alternative to a new seepage collection canal is to fill in the existing seepage collection canal for STA 3/4 Supply Canal. The Supply Canal would then serve to reduce the net driving head at the south side of the reservoir perimeter.

4. MODELING OF SEEPAGE CONTROL ALTERNATIVES

4.1 Modeling Method

The computer program SEEP/W was used for modeling of the seepage control alternatives. The program is licensed by GEO-SLOPE International, Ltd.

4.2 Model Parameters

The subsurface stratigraphy developed from the borings performed for the test cells was used in the seepage model which is the basis of the work presented in this Technical Memorandum. The model will be developed further as results of ground investigations become available. These conditions are described in detail in the Test Cell Construction and Seepage Monitoring Report. The stratigraphy was simplified for monitoring and modeling purposes. The hydraulic conductivity values used in the SEEP/W model are the values recommended by the Reservoir Seepage Analysis Technical Memorandum. Given the wide variation in the geology, these hydraulic conductivities were derived to represent the broad hydrogeological characteristics of the subsurface materials averaged over depth. Hydraulic conductivity values will be refined in the course of modeling with MODFLOW and as results of ground investigations become available.

The land surface at the test cell site and the entire site of the EAA Reservoir A-1 is covered with a black, highly organic, fine grained soil known locally as muck or peat, 1 to 2 feet thick. The muck is often underlain by several inches to 2 feet of calcareous clay locally called marl. The muck and marl constitute the local soil in the entire EAA. This muck layer will be removed from the construction areas and from under the embankment only. The muck layer is cut through by canals, roads and other shallow excavations. Given the lateral discontinuity and uncertain characteristics of the muck, it was conservatively excluded from the assessment.

Results from the EAA Reservoir A-1 Test Cells (reported in Test Cell Construction and Seepage Monitoring Report) were used to calibrate the hydraulic conductivities in a two-dimensional finite element model. The program SEEP/W by Geo-slope International was used to calibrate the results. SEEP/W is a finite element model rigorously formulated with hydraulic conductivity and water content as a function of pore-water pressure. This work is reported in the Reservoir Seepage Analysis Technical Memorandum.

In the calibration of the model, axisymmetric geometry produced the best correlation between the field values and model. This is logical given the radial nature of the flow between approximately 2000 linear feet of embankment and approximately 4000 linear feet of seepage collection canal. However, for the area of interest for this Technical Memorandum, namely relatively near the embankment on the main A-1 reservoir, plane geometry is more appropriate. In this near field location it was assumed that flow lines are parallel, not diverging in plan.

The following parameters were derived from the Test Cell Program data as described in the Reservoir Seepage Analysis Technical Memorandum. This work has been developed further and other sets of conductivities developed from work using the MODFLOW computer program. This work is described in the Groundwater Model Technical Memorandum. See Table 4-1.

Although the model results fitted the test cell data, the solution under these parameters was very sensitive to the conductivities in the Fort Thompson and the Caloosahatchee Formations. Further work to investigate the effect of cutoff wall permeability on the results is being performed (as described in the Groundwater Model Technical Memorandum). In view of this sensitivity, a range of parameters have been used in the work presented here. The parameters chosen were those used by the USACE on work reported in memorandums dated 2004, and 2005. In addition to the USACE values, some work had already begun on development of the MODFLOW model for the reservoir when this Technical Memorandum was written. Those values from MODFLOW have also been used below. The range of values is shown in Table 4-2.

4.3 Alternatives Modeled

The alternative seepage control scenarios modeled are described in Table 4-3. Figure 1 illustrates the individual components such as the relationship between seepage collection canal and embankment.

These cases are arranged to allow comparison of different factors on seepage. Cases 1, 2, and 3, and 6 and 7, show the impact of cutoff depth on seepage. Cases 1 and 4, and 5 and 6, show the impact of canal depth. Cases 1 and 5 show the impact of distance from the embankment to seepage collection canal.

4.4 Modeling Results

The results of the modeling of seepage control alternatives are listed in Tables 4-4 to 4-10.

4.4.1 Impact of Cutoff Depth

The results for seepage from the reservoir with the seepage collection canal 100 feet away from the embankment and held at 6 ft elevation are shown in the Figure 2. There is broad agreement in results between SEEP/W, MODFLOW and the USACE 2005 parameters at the 70 ft cutoff depth but significantly more loss is predicted by SEEP/W and MODFLOW for the shallowest cutoff through caprock.

4.4.2 Impact of Canal Depth

The results in Figure 3 indicate that seepage from the reservoir is increased by increasing the depth of the seepage collection canal. On the other hand, the results also show that a higher proportion of seepage is lost to the background when the canal is shallow (See Flow Lost, Tables 6-4 through 6-10).

4.4.3 Impact of Distance from the Embankment to Seepage Collection Canal

As Figure 4 indicates, total seepage is reduced when the distance of the seepage collection canal is increased. However, more water escapes from the system when the canal is further from the embankment.

4.4.4 Canal Water Level

When the water level in the canal is lower, seepage from the reservoir increases but less is lost to the background. So reducing the water level in the seepage canal has similar effect to deepening the canal.

5. GENERAL DAM AND FOUNDATION SEEPAGE CONTROL RECOMMENDATIONS

5.1 General

The following recommendations are based in part on observations during the test cell construction and on conversations with contractors.

5.2 Seepage Control in an Earthfill Embankment Dam

It is recommended that the seepage control in an embankment consist of a select fill core which was demonstrated to be effective during the test cell program. The zoning of the embankment should use the available materials economically, the filter relationship between zones should be maintained to prevent internal erosion, and sufficient drainage capacity should be provided to ensure that expected flows are carried freely.

The select fill core configuration should be based on the embankment section recommended in the Embankment Technical Memorandum.

5.3 Foundation Seepage Control

It is recommended that the seepage through the embankment foundation be controlled by a cutoff wall the depth of which will be decided after further design and modeling work. This wall should be soil-bentonite where strain compatibility between dam and cutoff is not a problem. A plastic concrete type cutoff wall would be more appropriate for a concrete dam.

This recommendation to include a cutoff wall is made for structural reasons as well as seepage quantity. The test cell program (Test Cell 1) demonstrated the vulnerability of the foundations when no cutoff is provided. On Test Cell 1, boils developed on the outside of the embankment. Over time similar features could develop into a serious problem around the perimeter of the reservoir. The general conditions around Test Cell 1 would not be acceptable in an embankment with a significant design life. Reservoir A-1 presents a significantly more difficult surveillance challenge than most dams due to its length. Most dams are routinely inspected closely on foot for signs of deterioration. Such close scrutiny will be hard to maintain in these circumstances, so anything which could become a future vulnerability, such as potential boils and aggressive leakage, should be avoided.

The dam design should make allowance for possible settlement of the material in the cut-off trench.

5.4 Seepage Collection

The seepage collection canal should have stable side slopes and the configuration should be compatible with operational and maintenance requirements. The canal depth will be determined by considering the efficiency of the system in capturing seepage in the foundation. This is considered further in the Groundwater Model Technical Memorandum. The canal width should be chosen to meet material supply needs (up to reasonable limits) and hydraulic requirements. Increasing the canal width reduces the area available for the reservoir. Material excavated form the seepage collection canal would be incorporated directly in to an embankment type dam. For a concrete gravity dam the material would only be used to form an upstream wave breaking bench. It would probably not be cost effective to haul borrow material from the perimeter canal to a process plant to manufacture concrete aggregate.

6. SPECIFIC SEEPAGE CONTROL CONSTRAINTS

6.1 General

Following the original release of this Technical Memorandum the groundwater control and seepage studies were extended. Much of the supplementary work was carried out using the MODFLOW computer program and is described in the Work Order 7 Groundwater Model Technical Memorandum. The description below concentrates on dam stability issues rather than water loss from the reservoir due to seepage.

6.2 US 27

Details of the US 27 cross sections have been requested by the District and the design can be refined when they are obtained. The reservoir design is required to keep groundwater level from rising into the sub-base of the road during a 25 year storm event (FDOT requirement per verbal communication). This will be achieved using a combination of the dam's cutoff wall, seepage collection canal and possibly a local drainage channel. The New North River, which is immediately adjacent to the road and with a higher water level than the A-1 Reservoir seepage collection canal, has a significant effect on the groundwater table in this area. This will be further evaluated and the solution refined for the BODR.

6.3 South Embankment (Adjacent to STA 3/4)

Two alternative reservoir alignments are possible along the existing STA 3/4 northern boundary. The earthfill embankment alignment would eliminate the seepage collection canal for the STA 3/4 supply canal and incorporate the northern canal bank within the new dam. In that case, seepage from the reservoir will pass directly into STA 3/4 which is considered to be a beneficial supply of water to the STA. Dam and foundation stability issues are accounted for because the water pressures in the STA supply canal balance the pressures emanating from the reservoir.

The other dam alignment provides a buffer area between the Reservoir A-1 dam and the existing seepage canal. This alignment would be necessary if a concrete gravity dam solution is selected for the project and would be similar to the configuration for the other sections of the reservoir using a combination of cutoff wall and seepage collection canal.

6.4 West Embankment (Adjacent to Holey Land)

This southern section of the west side of the reservoir is similar to the configuration described above for STA 3/4.

6.5 West Embankment (Adjacent to the future A-2 Reservoir)

The CERP envisages the whole of Compartment A developed as a reservoir. The area has been split in two, with Reservoirs A-1 and A-2 being designed and built separately. It is envisaged that the USACE will complete design and construction of Reservoir A-2 at some future date. Until Reservoir A-2 is complete, the dam separating the two areas must meet the same safety standards i.e. level of protection against seepage effects, as the rest of the dam. Stability of the dam and its foundation will be controlled using a combination of the dam's cutoff wall, seepage collection canal and possibly a local drainage channel. This will be further evaluated and the solution refined for the BODR.

6.6 North Embankment

The effect of the seepage from reservoir on the adjacent agricultural land has been modeled as described in the Groundwater Model Technical Memorandum. Stability of the dam and its foundation will be controlled using a combination of the dam's cutoff wall, seepage collection canal and possibly a local drainage channel. This will be further evaluated and the solution refined for the BODR.

7. REFERENCES

Engineering Manual No. 1110-2-1901, *Seepage Analysis and Control for Dams*, US Army Corps of Engineers, 30 September 1986.

Engineering Manual No. 1110-2-2300, *Earth & Rock-Fill Dams General Design & Construction Considerations*, US Army Corps of Engineers, 30 July 2004.

Seepage, Drainage, and Flow Nets, Harry R. Cedergren; John Wiley & Sons, Inc., First Corrected Printing, March, 1968.

Filling materials for watertight cutoff walls. International Commission on Large Dams Bulletin 51, 1985

Conversation with Dennis Collins of INQUIP on May 4, 2005.

TABLES

Table 1 Test Cell hydraulic conductivities (SEEP/W)

Stratum	Kh (ft/d)	Kv (ft/d)	Kv/Kh
Muck (not modeled)			
Caprock	400	1	0.0025
Fort Thompson	1000	4	0.004
Caloosahatchee	400	4	0.01
Tamiami	300	1	0.0033

Table 2 Hydraulic conductivity data

Layer		SEEP/W	MODFLOW	USACE 2004	USACE 2005
Caprock[1]	Kh (ft/day)	400	100	10	100
	Kv (ft/day)	1	2.5	1	10
Fort Thompson	Kh (ft/day)	1000	400	60/160[2]	60/200[2]
	Kv (ft/day)	4	15	25/40[2]	25/75[2]
Caloosahatchee[3]	Kh (ft/day)	400	1000	90	250
	Kv (ft/day)	4	4	45	125
Tamiami	Kh (ft/day)	300	400	36	36
	Kv (ft/day)	1	1	18	18

[1] Even though the caprock is the top of the Fort Thompson Formation, its unique hydrogeological conditions and position, it warrants distinction from the Fort Thompson Formation for hydrologic modeling purposes.

[2] Split into two layers in USACE studies.

[3] Caloosahatchee designated Lower Okeechobee/Fort Thompson by USACE 2004.

Table 3 Seepage Control Model

Model Case No.	Cutoff Depth from Top of Caprock (ft)	Seepage Collection Canal Distance from Toe of Embankment (ft)	Seepage Collection Canal Depth (ft)
Case 1	26	100	20
Case 2	70	100	20
Case 3	4	100	20
Case 4	26	100	10
Case 5	26	350	20
Case 6	26	350	10
Case 7	70	350	10

Table 4 Case 1 - Seepage canal 20ft deep 100 ft from toe, 26ft cutoff

Permeability Model	Canal Water Level	Total Flow (ft^3/hr)	Flow Lost (ft^3/hr)	Total head at d/s toe	Vert. Gradient. At d/s toe
	(feet) Elevation	per ft length of embankment	Per ft length of embankment	(feet) Elevation	
SEEP/W	6	22.88	4.73	6.53	-0.01
	8	20.66	6.61	8.40	-0.02
MODFLOW	6	36.50	8.56	9.50	-0.01
	8	33.09	10.27	10.97	-0.01
USACE 2004	6	28.28	1.44	11.07	0.01
	8	24.99	2.79	12.35	0.01
USACE 2005	6	23.92	0.01	11.45	0.00
	8	21.06	0.73	12.71	0.00

Table 5 Case 2 - Seepage canal 20ft deep 100 ft from toe, 70ft cutoff

Permeability Model	Canal Water Level	Total Flow (ft^3/hr)	Flow Lost (ft^3/hr)	Total head at d/s toe	Vert. Gradient. At d/s toe
	(feet) Elevation	per ft length of embankment	Per ft length of embankment	(feet) Elevation	
SEEP/W	6	9.08	4.14	6.10	0.00
	8	8.51	6.09	8.07	0.00
MODFLOW	6	11.41	6.11	6.34	0.00
	8	10.80	8.10	8.21	0.00
USACE 2004	6	26.65	1.35	10.56	0.01
	8	23.55	2.71	11.90	0.00
USACE 2005	6	10.92	0.05	8.13	0.00
	8	9.59	0.67	9.83	0.00

Table 6 Case 3 - Seepage canal 20ft deep 100 ft from toe, 4ft cutoff

Permeability Model	Canal Water Level	Total Flow (ft^3/hr)	Flow Lost (ft^3/hr)	Total head at d/s toe	Vert. Gradient. At d/s toe
	(feet) Elevation	per ft length of embankment	Per ft length of embankment	(feet) Elevation	
SEEP/W	6	37.75	4.51	9.61	-0.01
	8	33.79	6.42	10.83	-0.04
MODFLOW	6	40.49	8.62	10.94	0.00
	8	36.61	10.32	12.23	0.00
USACE 2004	6	28.37	1.45	11.12	0.01
	8	25.06	2.79	12.39	0.01
USACE 2005	6	25.13	0.02	11.79	0.00
	8	22.12	0.73	13.01	0.00

Table 7 Case 4 - Seepage canal 10ft deep 100 ft from toe, 26ft cutoff

Permeability Model	Canal Water Level	Total Flow (ft^3/hr)	Flow Lost (ft^3/hr)	Total head at d/s toe	Vert. Gradient. At d/s toe
	(feet) Elevation	per ft length of embankment	Per ft length of embankment	(feet) Elevation	
SEEP/W	6	20.99	6.20	6.95	-0.02
	8	19.20	7.72	8.69	-0.03
MODFLOW	6	33.92	10.16	10.23	-0.01
	8	31.05	11.52	11.54	-0.01
USACE 2004	6	24.02	3.48	12.67	0.01
	8	21.56	4.43	13.63	0.01
USACE 2005	6	23.32	0.32	11.70	0.00
	8	20.60	0.94	12.90	0.00

Table 8 Case 5 - Seepage canal 20ft deep 350 ft from toe, 26ft cutoff

Permeability Model	Canal Water Level	Total Flow (ft^3/hr)	Flow Lost (ft^3/hr)	Total head at d/s toe	Vert. Gradient. At d/s toe
	(feet) Elevation	per ft length of embankment	Per ft length of embankment	(feet) Elevation	
SEEP/W	6	20.59	4.38	8.80	-0.02
	8	18.63	6.64	10.36	-0.02
MODFLOW	6	30.27	8.29	13.16	0.00
	8	27.59	10.35	14.12	-0.01
USACE 2004	6	21.70	1.19	13.71	0.01
	8	19.20	2.81	14.67	0.01
USACE 2005	6	15.05	0.04	15.41	0.00
	8	13.22	0.80	16.21	0.00

Table 9 Case 6 - Seepage canal 10ft deep 350 ft from toe, 26ft cutoff

Permeability Model	Canal Water Level	Total Flow (ft^3/hr)	Flow Lost (ft^3/hr)	Total head at d/s toe	Vert. Gradient. At d/s toe
	(feet) Elevation	per ft length of embankment	Per ft length of embankment	(feet) Elevation	
SEEP/W	6	19.52	5.67	9.41	-0.02
	8	17.87	7.53	10.80	-0.02
MODFLOW	6	28.72	9.76	13.66	0.00
	8	26.44	11.44	14.49	0.00
USACE 2004	6	19.19	3.08	14.67	0.00
	8	17.28	4.24	15.40	0.00
USACE 2005	6	14.81	0.18	15.52	0.00
	8	13.06	9.46	16.28	0.00

Table 10 Case 7 - Seepage canal 10ft deep 350 ft from toe, 70ft cutoff

Permeability Model	**Canal Water Level**	**Total Flow (ft^3/hr)**	**Flow Lost (ft^3/hr)**	**Total head at d/s toe**	**Vert. Gradient. At d/s toe**
	(feet) Elevation	per ft length of embankment	Per ft length of embankment	(feet) Elevation	
SEEP/W	6	8.85	4.26	6.79	0.00
	8	8.32	6.29	8.50	0.00
MODFLOW	6	11.20	6.21	7.25	0.00
	8	10.62	8.27	8.75	0.00
USACE 2004	6	18.44	2.95	14.17	0.00
	8	16.61	4.13	14.95	0.00
USACE 2005	6	8.55	0.45	11.15	0.00
	8	7.53	0.83	12.45	0.00

FIGURES

Figure 1 Configuration Options

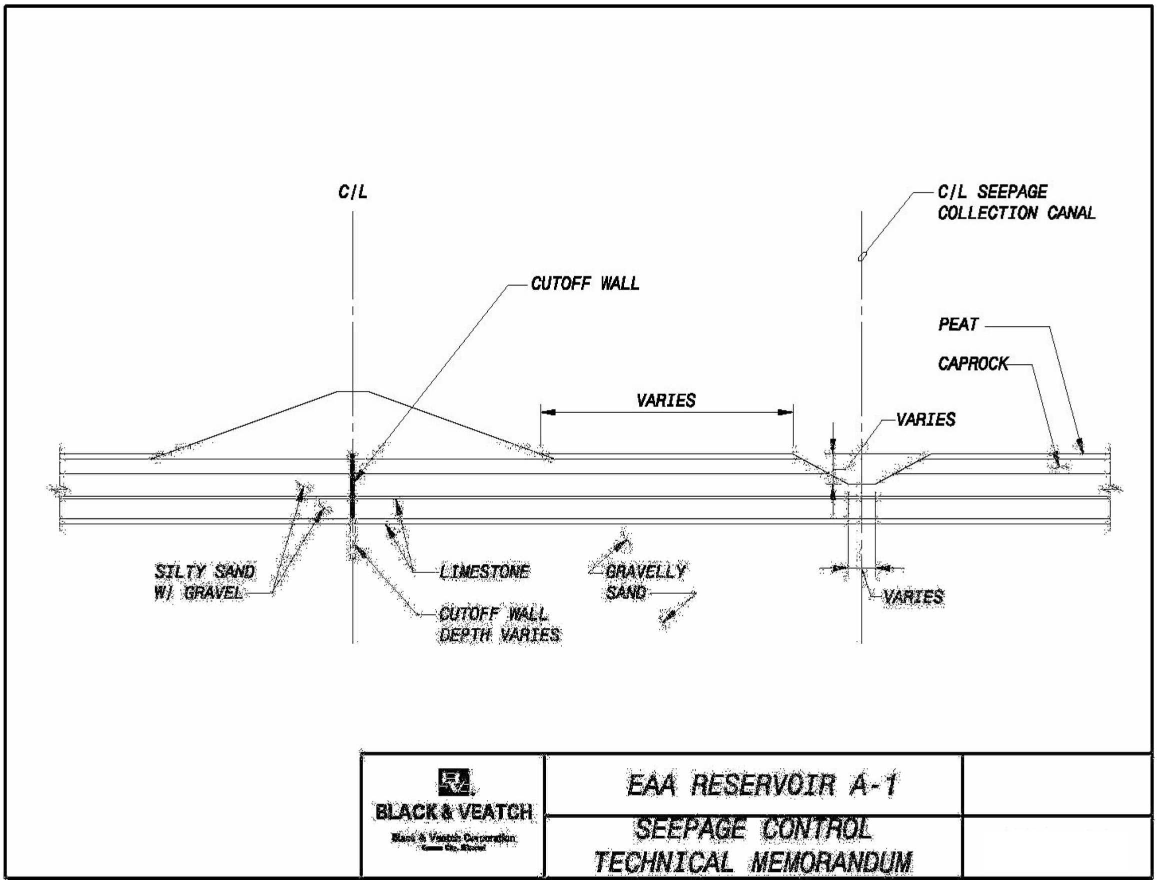

Figure 2 Seepage from Reservoir - Seepage Collection Canal 100 Feet Away From the Embankment and Held at 6 Ft Elevation

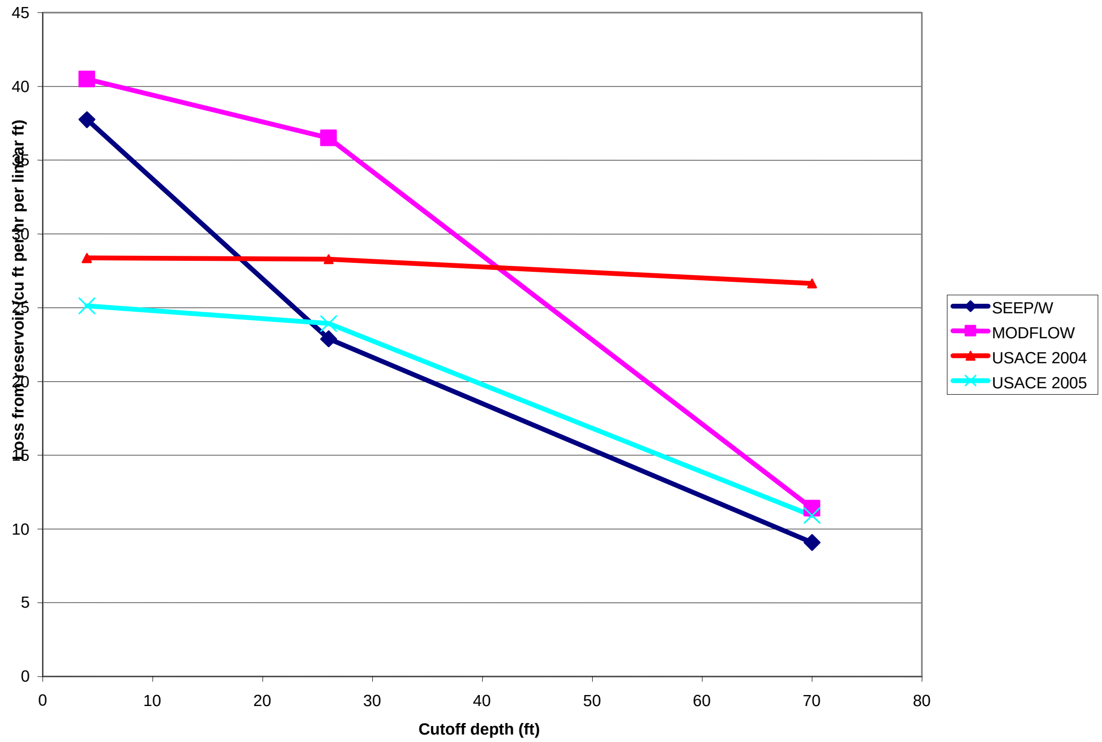

Figure 3 Seepage from Reservoir with Increased Depth of the Seepage Collection Canal

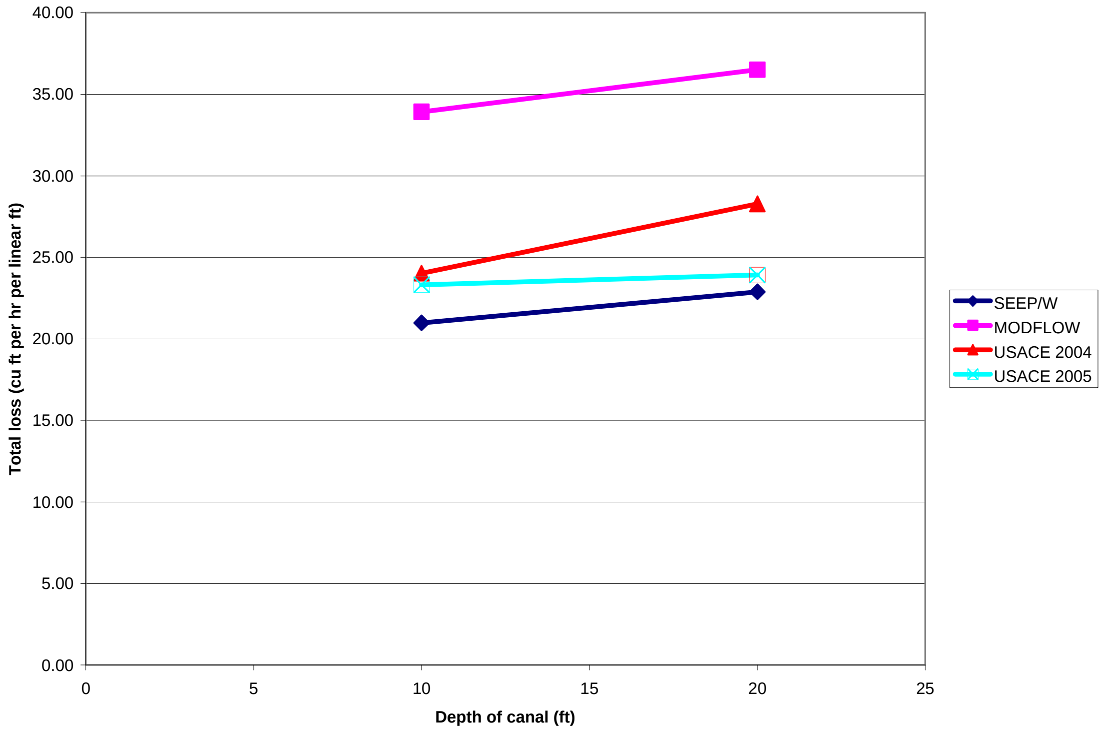

Figure 4 Seepage from Reservoir when Distance of the Seepage Collection Canal is Increased